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Crop Yield Response in the Punjab

By

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1. INTRODUCTION

The relationship between crop yields and irrigation water, fertilizer and new varieties is a crucial part of the green revolution and of agricultural development generally. Quantitative estimates of this relationship are useful in planning at the farm and regional level and for use in simulation models designed for projecting economic activity and policy analysis. In this paper we report results of a statistical analysis of crop yield response to fertilizer for traditional and new varieties under irrigated conditions.[1]

At the time of this study, appropriate experimental data existed only for traditional varieties grown under irrigated conditions. Response functions were estimated for these first using conventional methodology. The results are reported in Section 2. The remaining response affects, those for new high yielding varieties, had to be derived from these "objective relations" using some specific economic assumptions and data fragments. Our methodology, which we report in Section 3 together with the empirical estimates, is novel and may be useful to others who are forced to piece together the best estimates they can when complete data are unavailable.

In the concluding section of the paper we suggest adjustment of the estimated yield response functions to allow for average weather conditions.

2. TRADITIONAL CROPS UNDER IRRIGATION

In a given agronomic setting the yield of a crop using standard irrigation practices may be regarded as a function of the amount of nutrients added. Let the yield per acre be Y and the amount of nitrogen, phosphorus and potash be N, P and K respectively measured in kilograms (kgs.) per acre. Then we may write

$$(1) \qquad Y = f(N,P,K,)$$

A functional form widely used to approximate this relation is the quadratic function

$$(2) \qquad Y = \alpha_0 + \alpha_{n1} N + \alpha_{n2} N^2 + \alpha_{p1} P + \alpha_{p2} P^2 + \alpha_{k1} K + \alpha_{k2} K^2 + \alpha_{np} NP + \alpha_{nk} NK + \alpha_{pk} PK + \alpha_{npk} NPK.$$

The first term, α_0, represents all unaccounted for yield producing factors. The next six terms represent the independent affects of N, P and K while the last four terms represent the interaction affects.[2]

In most cases a soil is most deficient in one or the other of these three nutrients. If we fix all but this one we arrive at a single input relation shown in Figure 1. This curve assumes diminishing returns to a single nutrient which, in terms of equation (2) means that the coefficients of the squared terms are negative ($\alpha_{n2}, \alpha_{p2}, \alpha_{k2} < 0$). The effect of changing the application of the other nutrients, is to shift this curve. If the interaction terms are unimportant then the curves for the given nutrient would merely shift upward. When the interaction terms are important, then the curves change shape as well, with both the slope and biological maximum changing.

Interaction terms are frequently found to be relatively unimportant and can be safely ignored. This possibility was explored by estimating (2) and comparing it with a second estimate of (2) assuming that the four interaction terms could be left out. It was found that the interaction affects could indeed be safely ignored in most cases.

Experiments were carried out in 1964-65 at various Punjab Agricultural University Research Stations and on a number of cultivators' fields at different locations in different districts throughout the State under the direct supervision of the personnel from the Department of Soils. These carefully designed experiments included several levels, depending on the crop, of nitrogen, phosphorus and potash.

It was decided to limit our use of this data to the field trials.[3] These presumably came closer than the research station experiments to contemporary operating conditions of interest to us.[4] Twenty-four ob-

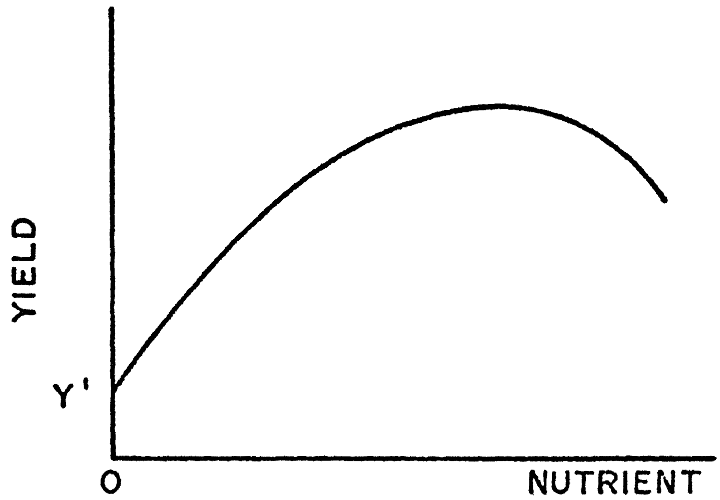

FIGURE 1: YIELD RESPONSE FOR A SINGLE NUTRIENT

servations were available for each of two districts. Functions were fit by least squares to each district data set with and without the interaction terms. The results are shown in Table 1. As can be seen, interdependence terms were insignificant (at the 5% level) except in the case of rice.[5] Since the last (NPK) coefficient for rice in equation (2) was very small it was dropped and a third equation estimated with the three other interaction terms present. This function was used in the further analysis. In most cases the amount of variation explained by the quadratic function was very high. This can be seen in the R^2 column of Table 1.

To obtain an estimate of yield response for the region as a whole, we averaged the coefficients from the several sources. This gave the figures shown in Table 2. The coefficients for P^2 and K^2 are positive in several cases, a result that may be interpreted as meaning that over the range of field trial nutrient levels, increasing returns were observed

Table 2: COEFFICIENTS FOR CENTRAL PUNJAB FERTILIZER YIELD RESPONSE FUNCTIONS FOR LOCAL, IRRIGATED CROPS

Crop	Constant	N	P	K	N^2	P^2	K^2
Wheat	17.4	.2174	.1127	.0038	-.0015	-.0008	.0007
Cotton	11.43	.0604	.0189	-.0172	-.0004	.00015	.0006
Rice	13.03	.1197	.052	a	-.0008	-.0002	a
Groundnut	14.9	.0256	.1126	.0677	-.0024	-.0009	-.0007
Bajra	12.3	.2212	.0708	-.0477	-.0027	-.00015	.0016
Sugarcane	450.5	1.8973	1.5249	-.2389	-.0048	-.0055	.0016

[a]A "very small" number.

Table 1: COEFFICIENTS OF QUADRATIC YIELD-FERTILIZER RESPONSE FUNCTIONS

Crop	District	Constant	N	P	K	N^2	P^2	K^2	NP	NK	PK	NPK	R^2	F*
WHEAT	Ludhiana	18.85	.161	.1157	.0584	-.0008	-.0008	-.0002	0.0001	-.0001	-.0025	.0000	.9712	
		(35.13)+	(6.07)+	(3.61)+	(1.51)	(2.12)*	(1.91)*	(.3048)	(.1955)	(.4187)	(1.18)	(1.62)		
	Ludhiana	18.77	.1659	.1325	.0776	-.0009	-.001	-.0005					.9314	0.47
		(47.34)+	(7.06)+	(5.08)+	(2.67)**	(2.72)**	(2.76)**	(1.11)						
	Patiala	17.45	.2087	-.0152	-.2273	-.0017	.0005	.0034	0.0012	.001	.0144	-.0002	.8766	
		(12.47)+	(3.02)+	(.1946)	(2.26)**	(1.72)	(.4138)	(2.45)**	(1.4)	(1.53)	(2.59)**	(2.79)**		
	Patiala	15.98	.2689	.0928	-.0852	-.002	-.005	.0018					.7894	2.29
		(12.67)+	(3.59)+	(1.12)	(.9197)	(1.94)+	(.4131)	(1.39)						
AMERICAN COTTON	Sangrur	9.44	.0543	.0214	-.0046	-.0002	.0002	.0003	-.0001	.0001	.0018	-.0000	.9542	
		(33.02)+	(6.63)+	(1.24)	(.294)	(3.21)+	(.7822)	(.9132)	(1.23)	(1.7798)	(1.55)	(1.68)		
	Sangrur	9.51	.0574	.0294	.0041	-.0003	-.0001	.0002					.9238	2.15
		(37.41)+	(6.56)+	(1.74)*	(.2173)	(3.76)+	(.2699)	(.719)						
	Patiala	12.97	.0692	.0292	-.0105	-.0005	.0004	.0005	-.0003	-.0001	-.0022	.0000	.6699	
		(17.07)+	(3.18)+	(.6389)	(.1906)	(2.53)**	(.5626)	(.6757)	(1.01)	(.1868)	(.7117)	(.7599)		
	Patiala	13.36	.0634	.0084	-.0385	-.0005	.0004	.0009					.632	0.359
		(24.19)+	(3.33)+	(.2295)	(.9364)	(2.99)+	(.7343)	(1.42)						
MAIZE	Ambala	11.91	.0867	.0933	-.0713	-.0003	-.001	.0012	.0002	-.0000	-.0003	.0000	.9496	
		(20.85)+	(5.31)+	(2.71)**	(1.72)	(2.41)**	(2.08)**	(2.18)**	(.9506)	(.9149)	(.1438)	(.2234)		
	Ambala	11.60	.0871	.0978	-.0604	-.0003	-.0008	.0011					.9404	0.59
		(27.1)+	(5.91)+	(3.43)+	(1.89)*	(2.27)**	(2.01)*	(2.39)**						
	Gurdaspur	10.74	.0403	.0227	-.0637	.0000	.0001	.0013	.0002	.0006	.0028	-.0000	.8919	
		(13.97)+	(1.66)	(.4972)	(1.13)	(.0169)	(.1269)	(1.729)	(.6464)	(1.26)	(.9126)	(1.26)		
	Gurdaspur	10.39	.0611	.0413	-.0269	-.0001	-.0001	.0009					.8635	0.86
		(17.73)+	(3.0)+	(1.06)	(.616)	(.7608)	(.1496)	(1.47)						
	Ludhiana	22.46	0.388	.1831	.0037	.0004	-.0021	.0001					.8388	0.71
		(18.24)+	(.9157)	(2.23)**	(.0404)	(1.17)	(1.79)*	(.0447)						
	Patiala	25.87	-.0061	.2677	-.079	.0011	-.0039	-.0003					.5705	0.17
		(8.98)+	(.0614)	(1.39)	(.3686)	(1.32)	(1.43)	(.001)						

Crop	District	Constant	N	P	K	N^2	P^2	K^2	NP	NK	PK	NPK	R^2	F*
RICE	Ambala	10.12	.1023	.0228	.0062	-.0006	.0002	.0004	.0005	.0004	.0066	.001	.9743	
		(22.76)+	(4.66)+	(0.8591)	(.1947)	(1.83)*	(.5103)	(.8954)	(1.97)*	(1.39)	(3.75)+	(3.89)+		
	Ambala	9.35	.1275	.0745	.0769	-.0007	-.0002	-.0004					.9413	4.138**
		(20.21)+	(4.65)+	(2.45)**	(2.26)**	(1.816)*	(.5215)	(.7183)						
	Ambala	10.63	.1145	.0505		-.001	-.003		.0006	.001	-.003		.9065	
		(17.71)+	(3.18)+	(1.20)		(1.89)*		(1.47)	(3.13)+	(.5838)				
	Gurdaspur	15.6018	.1253	.0489	-.0349	-.0006	-.0001	.0005	.0003	.0002	.0007	-.0000	.96	
		(28.48)+	(4.63)+	(1.49)	(.8856)	(1.55)	(.8712)	(.8912)	(.7477)	(.3457)	(.3031)	(.2792)		
	Gurdaspur	15.298	.1295	.0583	-.0185	-.0005	-.0000	.0003					.9569	0.255
		(38.97)+	(5.56)+	(2.25)**	(.6425)	(1.59)	(.0461)	(.7778)						
	Gurdaspur	15.43	.1249	.0545		-.0006	-.0001		.0002	.0001	.0000		.9575	
		(38.57)+	(5.20)+	(2.06)*		(1.69)	(.205)		(.6301)	(.3693)	(.0955)			
GROUNDNUT	Ludhiana	19.25	.2904	.1103	.1008	-.0042	.0001	-.0004	-.0015	-.0009	.0023	-.0001	.9288	
		(29.92)+	(3.74)+	(2.46)**	(1.86)*	(1.67)	(.1467)	(.5223)	(1.388)	(.7622)	(.6499)			
	Ludhiana	19.93	.2897	.1072	.0792	-.0061	-.0004	-.0004					.8847	2.02
		(33.94)+	(3.53)+	(2.48)**	(1.64)	(2.29)**	(.5607)	(.5422)						
	Patiala	9.8	.1291	.1168	.0549	.002	-.0013	-.0009	-.0007	-.0002	-.0004	.0000	.9168	
		(17.13)+	(1.86)*	(3.03)+	(1.18)	(.9066)	(2.09)*	(1.22)	(.7211)	(.1527)	(.3105)	(.2689)		
	Patiala	9.89	.1216	.1183	.0567	.0014	-.0015	-.0009					.912	0.186
		(24.27)+	(2.14)**	(3.95)+	(1.69)	(.7874)	(2.93)+	(1.58)						
BAJRA	Sangrur	17.49	.3988	.1255	-.108	-.0048	.0003	.0015	.0015	.0005	-.0016	.0000	.7916	
		(9.67)+	(4.46)+	(1.16)	(.8293)	(3.75)+	(.1705)	(.8934)	(1.33)	(.4226)	(.2185)	(.4351)		
	Sangrur	17.43	.382	.1076	-.1015	-.0048	.0000	.0021					.6964	1.48
		(11.57)+	(4.28)+	(1.09)	(.9173)	(3.84)+	(.0315)	(1.267)						
	Rohtak	7.31	.0557	.0286	-.0039	-.0006	-.0002	.0001	.0001	.0002	.0004	-.0000	.8459	
		(20.44)+	(3.15)+	(1.39)	(.1497)	(2.22)**	(.6119)	(.1767)	(.6595)	(.9712)	(2.767)	(.3463)		
	Rohtak	7.11	.0604	.034	.0061	-.0005	-.0002	.0000					.8332	0.26
		(27.69)+	(3.97)+	(2.01)*	(.3252)	(2.43)**	(.7448)	(.1162)						
SUGARCANE	Ambala	329.8	1.4586	1.1877	.2807	-.004	-.0035	-.0022	.0026	.0002	-.0136	.0001	.8979	
		(14.0)+	(2.46)**	(1.68)	(.3239)	(.9333)	(.6918)	(.3772)	(.7148)	(.0595)	(.5715)	(.6062)		
	Ambala	322.9	1.4157	1.1179	.2544	-.0024	-.0013	-.0018					.8862	0.37
		(18.69)+	(2.72)**	(1.94)*	(.3953)	(.6455)	(.3072)	(.3731)						
	Ludhiana	602.3	2.4967	.715	-.5942	-.0117	.0034	-.0073	-.0002	.0019	.0001	-.0000	.8957	
		(23.8)+	(3.92)+	(.9425)	(.6481)	(2.55)**	(.6232)	(1.1366)	(.0509)	(.4459)	(.0054)	(.0434)		
	Ludhiana	600.4	2.5439	.7167	-.5584	-.0017	.0031	.0078					.8934	0.071
		(33.78)+	(4.76)+	(1.21)	(.8436)	(3.080)+	(.7237)	(1.59)						
	Patiala	417.2	1.9776	3.1931	.2723	-.0045	-.0218	-.0016	.0008	-.0031	-.0362	.001	.7125	
		(10.3)+	(1.94)*	(2.63)	(.1856)	(.6229)	(2.5236)	(.1525)	(.1310)	(.467)	(.8873)	(.8944)		
	Patiala	428.4	1.7325	2.7402	-.4128	-.003	-.0183	.0013					.6865	0.294
		(14.58)+	(1.96)*	(2.8)**	(.3772)	(.4741)	(2.578)**	(.1544)						

for these nutrients. Since in practice, only two levels for P and K were used, zero and experimentation station recommended levels, this did not cause any troubles in the further analysis. Ideally, average functions for the region should be obtained from data for each of the five districts in the area. While this could not be done because of a lack of data a comparison of the expected yield at zero level of fertilization with actual average yield in 1964-65 indicated that these estimates are well within the range of experience.

Setting P and K at their recommended levels for each crop we obtain the one dimensional yield-nitrogen functions shown in Figure 2.

3. NEW VARIETIES

Yield-fertilizer response functions for new varieties could be obtained in the manner just described if experimental data were available. However, no reported results for experiments conducted either at agronomic stations or on cultivators' fields were available. The main reason for this deficiency was lack of time to initiate controlled experiments due to the recent development and introduction of the new varieties. However, a few field trials had been conducted for the latter using levels of fertiliza-

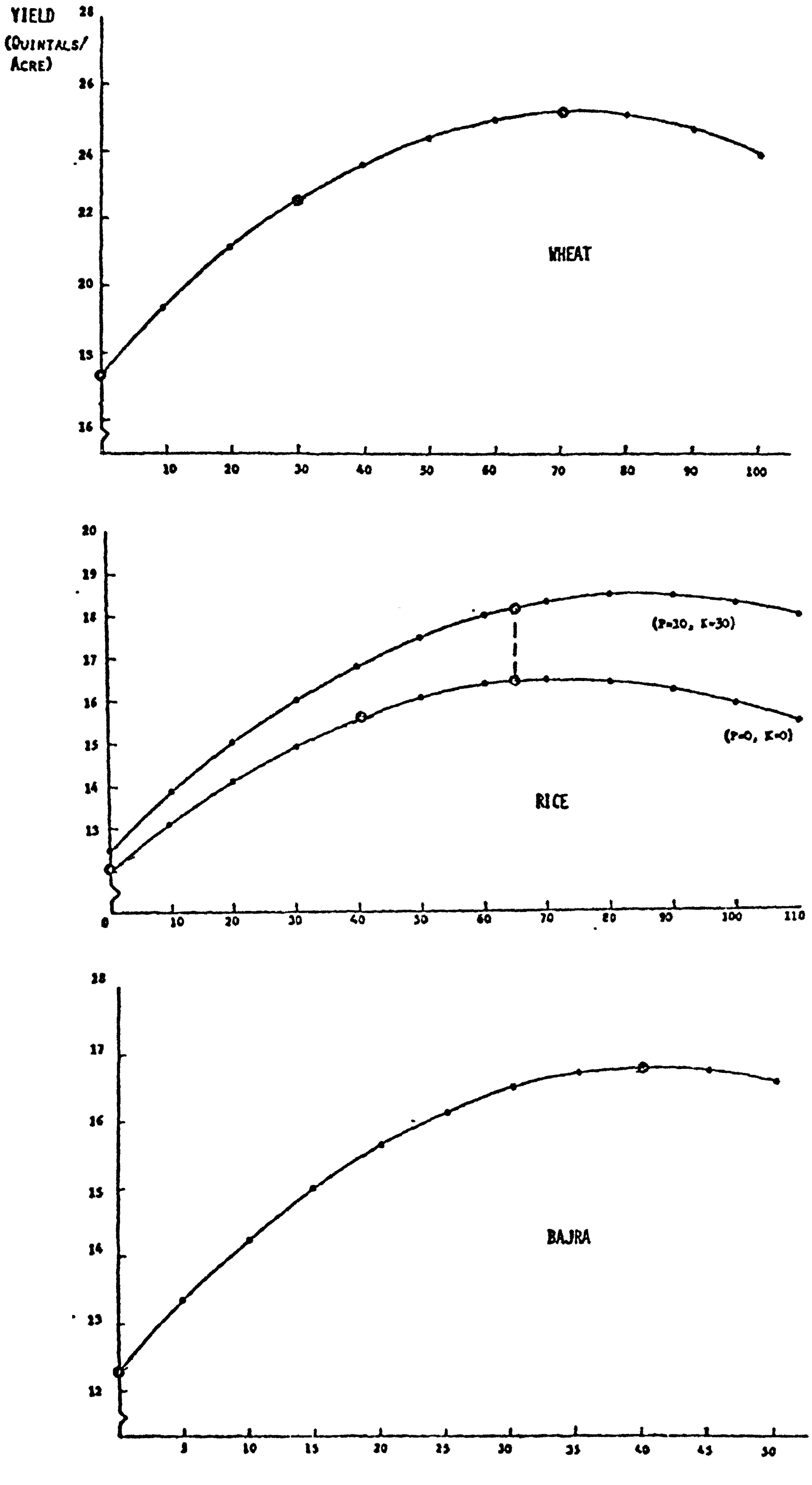

FIGURE 2: YIELD-FERTILIZER RESPONSE OF IRRIGATED, LOCAL CROPS

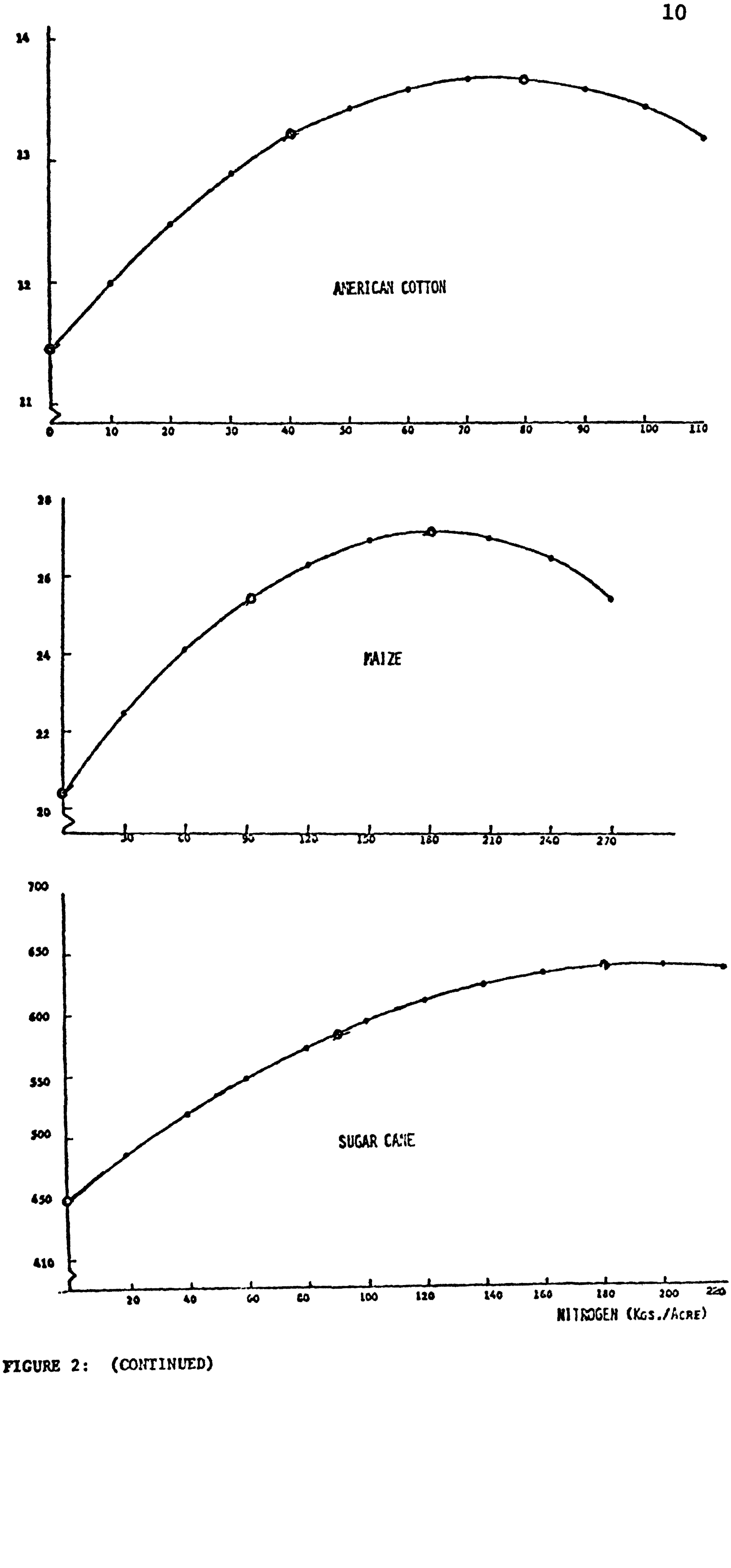

FIGURE 2: (CONTINUED)

tion recommended by the Directorate of Extension Education Punjab Agricultural University, Ludhiana. These fertilizer recommendations and the expected yields associated with them by the Directorate are shown in Table 3. This table contains similar data for the unimproved, local varieties.

Table 3: FERTILIZER RECOMMENDATIONS AND EXPECTED YIELDS FOR CENTRAL PUNJAB

		Recommended Fertilization[a]			
Crop	Variety	N	P	K	Yield[b]
Wheat (Local)	C 273	44.5	22.0	26.7	29.7
Wheat (High Yield)	PV 18	138.4	67.2	51.9	54.5
Maize (Local)	Local	61.3	15.6	37.1	29.7
Maize (Hybrid)	Ganga 101	113.9	36.3	44.5	44.5
Rice (Local)	Jhona	57.3	10.4	29.6	37.1
Rice (High Yield)	TN 1	74.1	20.8	58.2	49.4
Bajra (Local)	Local	49.4	23.7	29.6	24.7
Bajra (Hybrid)	Hybrid No. 1	123.5	19.8	74.1	44.5

Source: Directorate of Extension Education [1967-8, 1968-9].

[a]k.g./acre [b]quintals/acre

For some purposes it might be adequate to use these data directly. For others it would be quite useful to have functions of the form estimated in section 2. Using a few assumptions the data of Table 3 can be combined with the estimates of Table 2 to obtain average yield-fertilizer response functions for new varieties. Let us see how this can be done. (Readers only interested in the resulting relationships may skip over the technical material to Table 5 and Figure 5).

We adopt the following assumptions

I. Varietal differences affect only the constant (α_0) and nitrogen response coefficients (α_{n1}, α_{n2}). The phosphorus, potash and interaction terms are unaffected by varietal improvement.

II. Recommended nutrient levels as shown in Table 3 are economic optima for yield response with 'average' weather.

The first assumption is clearly not true but the relative economic importance of nitrogen justifies special attention while subsuming less important distinctions.[6] This assumption reduces the number of new parameters to be estimated for each new variety to three.

We have now in addition to (2) a quadratic response equation for new varieties

$$Y^* = \beta_0 + \beta_{n1} N + \beta_{n2} N^2 + \alpha_{p1} P + \ldots \quad (3)$$

where the remaining terms are the same as in (2).

Using field trial data for new varieties when no fertilizers are added we obtain the estimates given in Table 4[7] for the constant coefficient β_0.

Table 4: ESTIMATE OF β_0 FOR NEW VARIETIES

Wheat	17.4
Maize	22.4
Rice	15.0
Bajra	15.0

This leaves the nitrogen coefficients β_{n1} and β_{n2} for estimation. These can now be obtained from Table 3 by exploiting assumption II.[8]

The affect of this assumption is to define an equation between the parameters of (2) and those of (3). Let

$$\pi = pY - q_n N - q_p P - q_k K \tag{4}$$

be the gross profit per acre for a given crop. Since Y is a function of N, P and K, and holding P and K fixed, we get for the first order condition of a maximum:

$$\frac{\partial\pi}{\partial N} = p[\alpha_{n1} + 2\alpha_{n2}N^r + (\alpha_{np}P^r + \alpha_{nk}K^r + \alpha_{npk}P^rK^r)] - q_n = 0 \tag{5}$$

for traditional varieties and

$$\frac{\partial\pi}{\partial N_*} = p[\beta_{n1} + 2\beta_{n2}N^r_* + (\alpha_{np}P^r_* + \alpha_{nk}K^r_* + \alpha_{npk}P^r_*K^r_*)] - q_n = 0 \tag{6}$$

for new varieties. These equations are illustrated in Figure 3 which shows the points at which the slope of the yield response function, that is, the marginal product of nitrogen, equals the price ratio q/p.[9]

Equating (5) and (6) and eliminating p and q_n we get a single equation in the unknown β_{n1} and β_{n2}.

$$\beta_{n1} + 2\beta_{n2}N^r_* = \alpha_{n1} + 2\alpha_{n2}N^r + [\alpha_{np}(P^r-P^r_*) + \alpha_{nk}(K^r-K^r_*) + \alpha_{npk}(P^rK^r - P^r_*K^r_*)] \tag{7}$$

Table 3 implies the equation

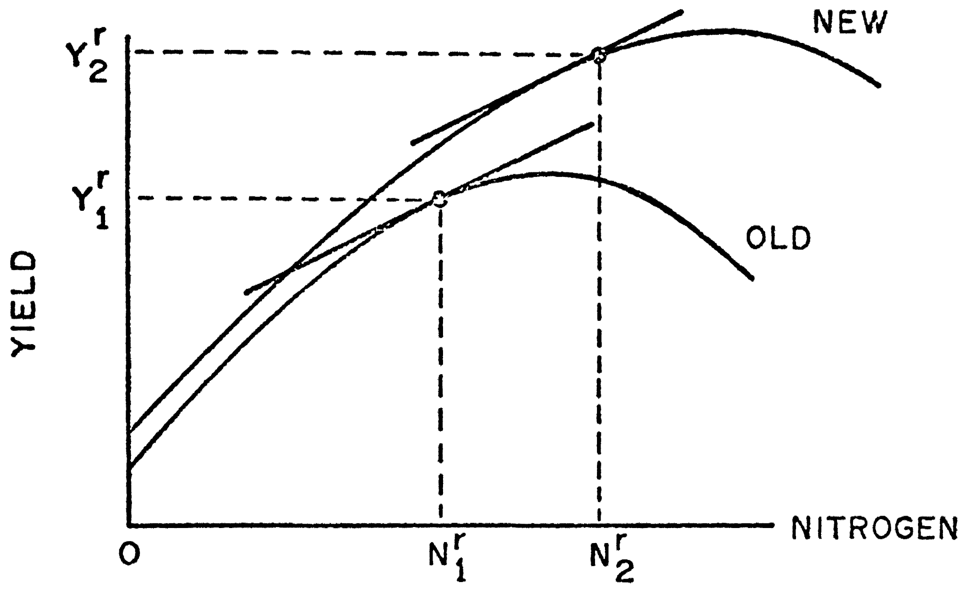

FIGURE 3: ECONOMIC OPTIMA FOR NEW AND OLD VARIETIES.

$$Y_*^r = \beta_0 + \beta_{n1} N_*^r + \beta_{n2} (N_*^r)^2$$

from which we obtain

(8) $$\beta_{n1} N_*^r + \beta_{n2} (N_*^r)^2 = Y_*^r - \beta_0$$

Solving (7) and (8) for the unknown parameters we get

(9) $$\beta_{n1} = (2B - AN_*^r)/N_*^r$$

(10) $$\beta_{n2} = (AN_*^r - B)/(N_*^r)^2$$

in which $A = \alpha_{n1} + 2\alpha_{n2} N^r + [\alpha_{np}(P^r - P_*^r) + \alpha_{nk}(K^r - K_*^r) + \alpha_{npk}(P^r K^r - P_*^r K_*^r)$ and $B = Y_*^r - \beta_0$. Because the interaction terms are assumed zero for each crop but rice, (9) and (10) are quite simple in these cases. Estimates for β_{1n} and β_{2n} obtained in this way are shown in Table 5.

Table 5: ESTIMATED NITROGEN RESPONSE COEFFICIENTS FOR NEW VARIETIES

Crop	β_{1n}	β_{2n}
Wheat	0.364077	-.0010122
Maize	0.307402	-.00096274
Rice	0.81132[a] (0.83874)	-.00521797
Bajra	0.3981	-.0017785

[a]Adjusted for interaction affects. The figure in brackets is the figure for P = 20.8 and K = 58.2.

The yield response functions for new varieties using equation 3 are illustrated in Figure 4.

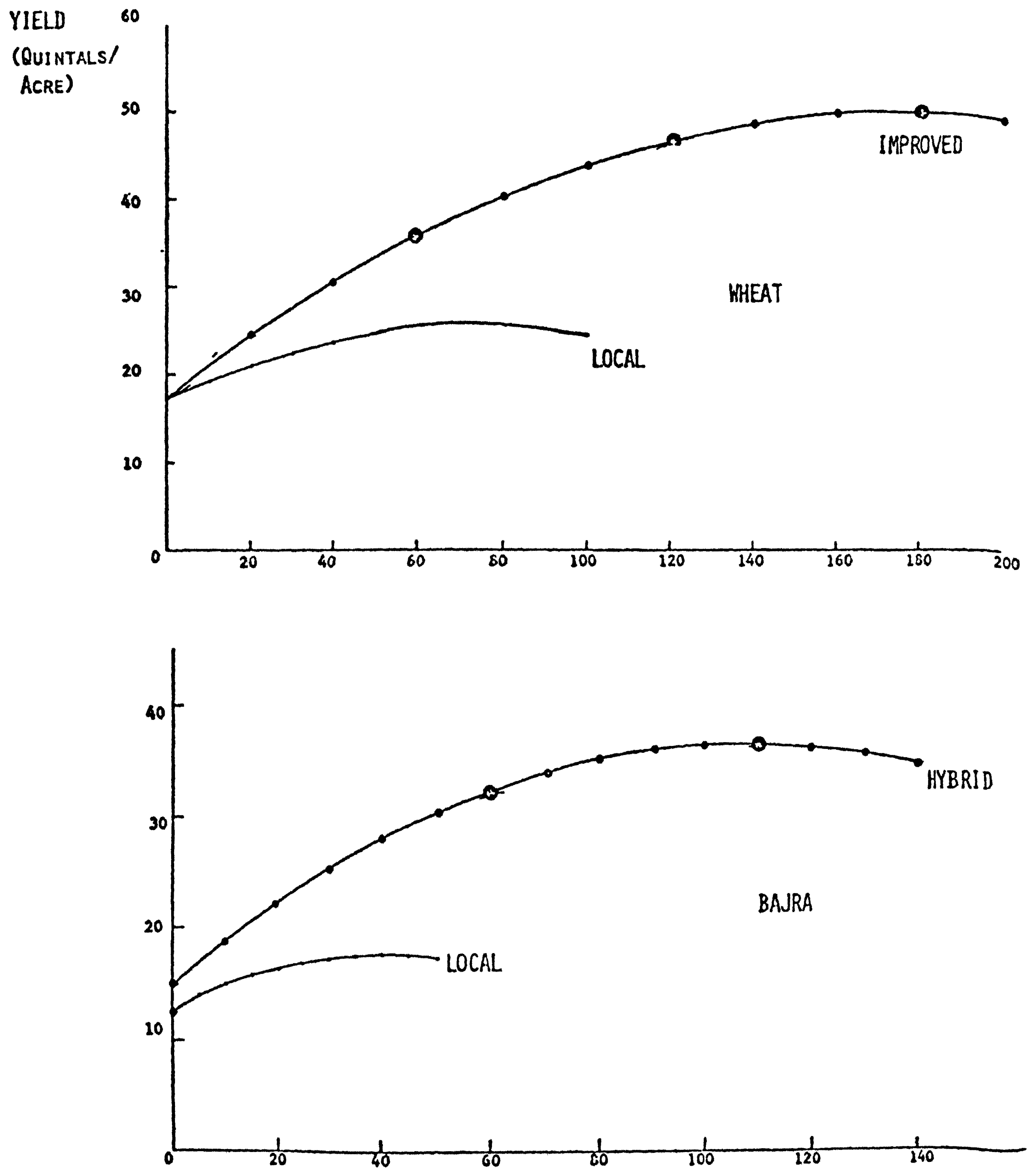

FIGURE 4: YIELD-RESPONSE FOR IRRIGATED NEW VARIETIES

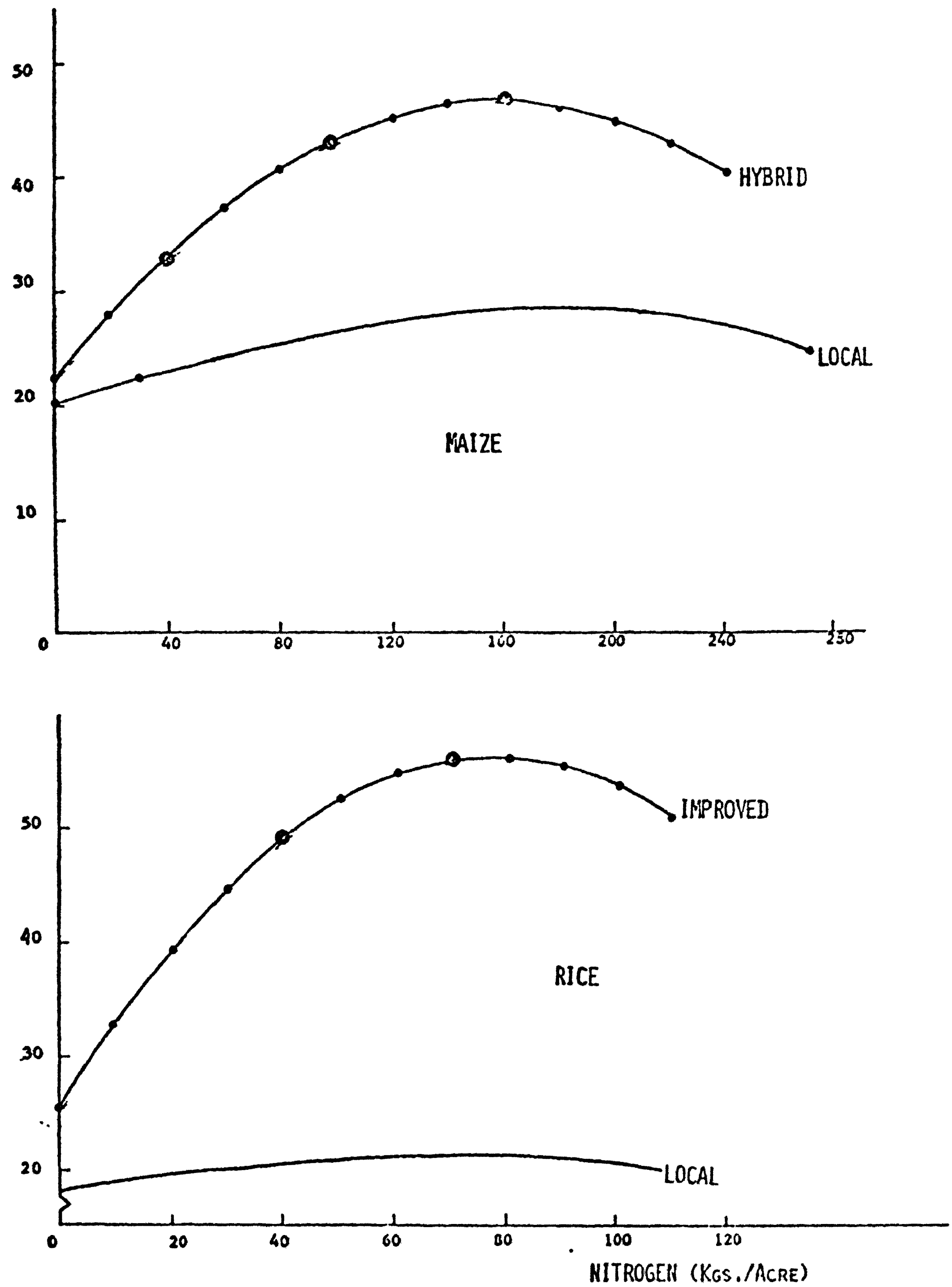

FIGURE 4: (CONTINUED)

4. ADJUSTMENT FOR AVERAGE WEATHER

All the yield response functions obtained above were derived from field experiments for the cropping year 1964-65, and include implicitly the weather effects peculiar to that year. Even if the systematic variations in yields due to variety, water use and fertilizer level are unaffected by weather and were to remain constant, yields will still vary from year to year, due to the effects of weather. In order to account for this, base yields representing "average weather" were estimated. These are reported below in Table 6.

Table 6: BASE YIELDS FOR THE CENTRAL PUNJAB

Activity	Estimated Base Yield (In Quintals/Acre)
Wheat (local) unirrigated	2.82
Wheat (local) irrigated	5.43
Wheat (high yield) irrigated	5.43
Gram (local) unirrigated	4.40
Gram (local) irrigated	5.58
Barley (local) unirrigated	2.75
Cotton (Desi) irrigated	0.83 (2.0)[a]
Cotton (American) irrigated	1.04 (3.0)[b]
Maize (local) unirrigated	3.09
Maize (local) irrigated	6.32
Maize (high yield) irrigated	7.08
Rice (local) irrigated	4.93
Rice (high yield) irrigated	5.67
Groundnut (local) unirrigated	2.39
Groundnut (local) irrigated	3.19
Bajra (local) unirrigated	1.27
Bajra (local) irrigated	2.54
Bajra (high yield) irrigated	3.10
Sugarcane (local) irrigated	137.8[b]

The method by which these figures were obtained is described elsewhere. It is suggested that these figures replace the constant terms of the estimated functions of tables. The reader will note that according to these "average" figures 1964-65 must have been an extraordinarily good year, or yield response on the field trial plots was greatly above what one can expect to be attainable in the region as a whole.[10]

NOTES

[1]This paper includes material originally reported in Inderjit Singh [1972, pp. 112-141, 357-397].

[2]Basic material on yield response and functional form is in Heady and Dillon [1964], OECD [1966] and Tisdale and Nelson [1966]. See also Brown et al. [1957], Baum et al. [1957], Heady et al. [1955] and Heady [1957].

[3]The data used here were compiled by Mr. Tilak Raj of Punjab Agricultural University and were made available through the courtesy of Professor S.S. Johl, Chairman, Department of Economics and Rural Sociology. They were originally reported in the 1965-66 Annual Report of the Department of Soils, P.A.U., Hirsar.

[4]Even here, however, an upward bias over average yields might be expected. It is likely, for example that farmers who cooperated in such experiments possessed greater managerial abilities and had more frequent contacts with the extension personnel. Aggregate regional analysis using their data would therefore tend to overestimate production.

[5]To test the hypotheses that the interaction terms are insignificant an F test was used. The statistic in this case is

$$F^* = \frac{RSS^2_{NI} - RSS^2_{I}}{(N-k_2) - (N-k_1)} \div \frac{RSS^2_{I}}{(N-k_1)}$$

where RSS^2_{NI} = the residual sum of squares from the equation with no interaction (equation II); RSS^2_{I} = the residual sum of squares from the equation with interaction (equation I); N = the number of observations in equations; k_1 = the number of independent variables in equation I; and k_2 = the number of independent variables in equation II.

For all estimated equations there are 24 observations, and 13 degrees of freedom for equation I and 17 degrees for equation II.

With regard to the "t" statistic for the test of the significance of the coefficients, an *, indicates a 10 per cent level of significance, ** indicates a 5 per cent level of significance, and + a 1 per cent level of significance with the appropriate degrees of freedom for the equation under consideration. The "t" statistic is given in parentheses under each coefficient.

F* statistic testing the significance of interdependence has to be greater than 3.18 to reject the null hypothesis that there is no interdependence among the nutrient inputs. This is the value of the F distribution at a 5 per cent level of significance with 4 and 13 degrees of freedom.

[6]In 1964-65 there were some 95,000 metric tons of N distributed compared to some 4,000 metric tons of phosphorus in Punjab and Haryana. See Statistical Abstract of Punjab, 1965, E.S.O. Punjab, and D.R. Bhumbla, N.S. Randhawa, and B. Das (1966).

[7]Raghbir Singh, P.A.U. assisted in these estimates.

[8]According to agronomists at P.A.U., the recommendations are thought to satisfy assumption II.

[9]For economic analysis of this kind see the references of note 2. In addition see also Seth and Abraham [1965], Baum, Heady and Blackmore [1956] and Heady and Pesek [1960].

[10]See note 4 above.